Appendix D
Toxins

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Acronyms and Abbreviations

µg/l	micrograms per liter
AWQC	ambient water quality criteria
CM	Conservation Measure
Cu	copper
DBR	California Department of Boating and Waterways
DOC	dissolved organic carbon
EDC	Endocrine-disrupting compounds
EEQ	estradiol equivalent
FRV	Final Residual Value
kg/yr	kilograms per year
ng/l	nanograms per liter
NPDES	National Pollutant Discharge Elimination System
NTR	National Toxics Rule
OEHHA	Office of Environmental Health Hazard Assessment
PCBs	Polychlorinated biphenyls
POD	pelagic organism decline
TMDL	total maximum daily load
WWTPs	wastewater treatment plants

D.1 Executive Summary

Table D-1 below provides an overview of the conclusions drawn from the toxins analysis. The color coding in the table is based on the following criteria.

None—Areas identified with potential for preliminary proposal–related increase in toxins *do not correspond with species/life stage occurrence. (applies if there is fish occurrence, but no toxins).*

Low—Areas identified with potential for preliminary proposal–related increase in toxins *correspond with species/life stage occurrence, but evaluation shows little potential for effects.*

Moderate—Areas identified with potential for preliminary proposal–related increase in toxins *correspond with species/life stage occurrence, and evaluation shows moderate potential for effects.*

High—Areas identified with potential for preliminary proposal–related increase in toxins *correspond with species/life stage occurrence, and evaluation shows high potential for effects based on mobilization of toxins into the foodweb and effects on covered species.*

Table D-1. Preliminary Proposal–Related Effects on Toxins and Occurrence of Covered Species in Preliminary Proposal Plan Area

		BDCP Regions							
Species	**Life Stage**	**Yolo Bypass**	**Cache Slough**	**North Delta**	**West Delta**	**Suisun Bay**	**Suisun Marsh**	**East Delta**	**South Delta**
Delta smelt	Eggs								
	Larva								
	Juvenile								
	Adult								
Longfin smelt	Eggs								
	Larva								
	Juvenile								
	Adult								
Steelhead	Egg/Embryo								
	Fry								
	Juvenile								
	Adult								
Winter-run Chinook salmon	Egg/Embryo								
	Fry								
	Juvenile								
	Adult								
Spring-run Chinook salmon	Egg/Embryo								
	Fry								
	Juvenile								
	Adult								
Fall-/late fall–run Chinook salmon	Egg/Embryo								
	Fry								
	Juvenile								
	Adult								

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Sacramento splittail	Egg/Embryo								
	Larvae								
	Juvenile								
	Adult								
White sturgeon	Egg/Embryo								
	Larva								
	Juvenile								
	Adult								
Green sturgeon	Egg/Embryo								
	Larva								
	Juvenile								
	Adult								
Pacific lamprey	Egg/Embryo								
	Ammocoete								
	Macropthalmia								
	Adult								
River lamprey	Egg/Embryo								
	Ammocoete								
	Macropthalmia								
	Adult								

Notes:

Probability of occurrence in area:

- Little
- Low
- Medium
- Likely

D.2 Organization of Appendix

The purpose of this toxins analysis is to evaluate how potential changes to toxins caused by the preliminary proposal could affect covered species. To do this, the appendix provides a general overview of toxic constituents currently present in the Bay-Delta aquatic ecosystem, identifies and assesses any changes in toxins that could result from implementation of the preliminary proposal, and describes how those changes could result in changes in exposure of covered species to toxins. This appendix focuses on toxic contaminants; water quality parameters, including salinity, turbidity, and temperature, are integrated with the hydrologic flow analyses and are discussed in a separate appendix.

This appendix presents a discussion of the toxins that are widely recognized as significant to determining the potential of the Bay-Delta ecosystem to support covered species. The approach is to develop qualitative conceptual models that describe how each toxin becomes available to biota. The conceptual models draw from those developed by the DRERIP, along with other relevant information sources. The analysis focuses only on changes in toxins that are directly attributable to the preliminary proposal actions that could affect covered species.

The first step of the analysis identifies effects on water quality that are directly attributable to preliminary proposal actions. The second step evaluates the potential for these changes in water quality to affect covered species, at what life stages, and where in the preliminary proposal study area. Effects of toxins on foodwebs are discussed in a separate appendix. Quantitative analyses will be used where they are useful in describing effects, and if data inputs and available analytical and modeling tools are deemed sufficient to provide reliable results. In particular, quantitative models developed for mercury and selenium exposures will be referenced.

The general approach to the analysis for each toxic constituent is outlined below.

1. Determine effects of preliminary proposal actions on potentially toxic constituents in the Delta ecosystem
    a. Describe the environmental chemistry of each parameter, the source of the element, how it is transported in the environment, and where it tends to accumulate
    b. Discuss preliminary proposal actions that could result in changes in toxic water constituents, at what locations and when (if there is a seasonal component)
2. Determine effects of changes in potentially toxic constituents on covered species
    a. Compare the spatial/temporal occurrence of each covered fish species/life stage with changes in toxins, identifying where changes in toxins coincide temporally and spatially with the presence of covered species
    b. Discuss how preliminary proposal–induced changes to toxins could affect covered species in the Bay-Delta; the discussion will be organized by species and life stage

D.3 Overview of Water Quality Stressors

Human activities that modulate, influence, or control the suitability of habitat for species and life stages are referred to as *stressors* (Nobriga and Herbold 2009). Stressors act on the environment by changing flow, water quality, temperature, or other attributes that determine the suitability of habitat for a species.

Toxins have been identified as stressors in the Bay-Delta ecosystem and have been associated with the pelagic organism decline (POD) (Baxter et al. 2010; Glibert 2010). Some of these toxins are contaminants that have been introduced to the ecosystem, and others are naturally occurring constituents in the Bay-Delta that have been mobilized and/or concentrated by anthropogenic activities. Although contaminants in water can be directly lethal to biota at very high concentrations, contaminants usually occur at concentrations much below lethal levels, enter the food chain at lower trophic levels, and can become more concentrated higher up in the food chain. Sublethal levels in fish result in various effects, including impaired growth and reproduction, or increase in the organism's susceptibility to disease (Werner et al. 2008).

This appendix provides a general description of the current state of toxins in the Delta and identifies potentially toxic constituents that are significant stressors to the ecosystem, changes that could occur in these parameters as a result of the preliminary proposal, and the potential effects of those changes on covered species.

D.3.1 Selection of Water Quality Stressors for Analysis

Water quality characteristics and the presence of contaminants (toxins) in the environment are determined by both natural conditions and land use. The primary land uses affecting water quality in the Bay-Delta include historical mining operations in the mountains drained by Delta tributaries, agriculture in the Bay-Delta, discharges related primarily to rural human habitation (wastewater), and discharges related to urban development (stormwater runoff, municipal wastewater, industrial wastewater). The types of contaminant issues typically associated with these land uses are presented in Table D-2 and discussed further in the following paragraphs.

Table D-2. Land Use and Typically Associated Contaminant Issues

Land Use	Typical Discharges to Water	Typical Contamination Issues
Mining (historical)	Concentrated mining waste	Mercury and Copper (specific to mining operations local to Bay-Delta)
Agricultural	Fertilizers Pesticides	Nutrients (ammonia) Copper Pesticides
Rural human habitation	Wastewater discharge	Nutrients
Urban development	• Municipal wastewater treatment plant discharge • Stormwater runoff • Industrial waste discharges	• Nutrients (ammonia), pesticides • Metals, pesticides, petroleum residues (PAHs) • Metals, PCBs (from historical discharges)

Historical mining of mercury and gold resulted in concentrating and mobilizing certain metals that occur naturally in the mountains of the upper tributaries. Metals are present in rocks, soils, and sediments to varying degrees, dependent on the source rocks. During the mining process, naturally occurring metals were mobilized, transported via streams, and deposited in sediments of the Bay-Delta marshes, wetlands, and streambeds.

Agriculture has been the primary land use in the Delta for more than a century; 538,000 acres of the 738,000 acres that compose the Delta (73%) are used for agriculture (Wood et al. 2010). The pesticides, herbicides, and fertilizers applied to agricultural lands throughout the Delta are present in the soils where they were applied but also have migrated off the farmed properties via air, groundwater, runoff, and rivers and are dispersed throughout all environmental media in the Delta ecosystem. Three families of pesticides have been used in the Delta—organochlorides (DDT, etc.) were used historically and now are banned, and pyrethroids and organophosphates are currently in use.

Rural developments associated with agricultural land use have minimal water quality impacts. The main types of discharges are relatively small volumes of wastewater, typically through local septic systems.

Cities and towns account for only 9% of the total Delta area; the main urban centers are the cities of Sacramento and West Sacramento located on the Sacramento River, and the city of Stockton located on the San Joaquin River (Wood et al. 2010). Water quality issues typically associated with urban development are related to stormwater discharges characterized by varying levels of metals, pesticides, and hydrocarbons that can accumulate in river sediments over time. Historically, Polychlorinated biphenyls (PCBs) often were associated with urban discharge, and these contaminants have been detected in fish tissues in the San Francisco Bay, although there is little research on PCB levels in the Bay-Delta. Wastewater discharges from treatment plants also are associated with urban and suburban land use. Although urban development accounts for a small percentage of land use in the Delta, discharges from wastewater treatment plants have had considerable impacts on nutrient levels, specifically ammonia, in the aqueous environment.

Given the relatively small amount of urban land area in the Delta (approximately 9%), urban-related contaminants such as lead, PCBs, and hydrocarbons also are discussed in less detail in this appendix. These contaminants typically are associated with historical wastewater, stormwater, and industrial discharges and tend to accumulate near the source, although some of them, such as PCBs, are known to bioaccumulate in the foodweb. Sacramento wastewater treatment plant discharges have also been shown to contain toxic levels of pesticides, including pyrethroids (Weston, 2010). Although this will be discussed, it should be noted that the north Delta intakes are downstream of the Sacramento Wastewater Treatment Plant (WWTP) discharge and would not affect dilution of effluent.

Endocrine-disrupting compounds will be discussed, but also in less detail. Endocrine-disrupting compounds include some of the toxins already described, particularly pesticides. They are referred to as *emerging contaminants* and are the subject of ongoing research. Endocrine-disrupting compounds include many different types of chemicals from a wide range of sources with widely varying chemical attributes, and their distribution in the Delta is not yet fully understood.

Other Stressor Conservation Measure (CM) 13, Nonnative Aquatic Vegetation Control, would involve applying existing methods used by the California Department of Boating and Waterway's (DBR's) *Egeria densa* and Water Hyacinth Control Programs. A brief summary of the types of herbicides used and the known toxic effects is included in this analysis.

The environmental toxins discussed below were selected based on historical and current land use along with published literature regarding water quality in the Bay-Delta and the types of toxins that have effects on fish.

- Mercury and methylmercury
- Selenium
- Copper
- Ammonia/um
- Pesticides
  - Pyrethroids
  - Organochlorines
  - Organophosphates

D.4 Methods

A qualitative approach was taken to evaluate the potential effects of preliminary proposal conservation measures on toxics in the Delta environment, and the possible effects on covered species. The effects on covered species are dependent more on the increase in both bioavailability and concentration of a given toxin, rather than just the increase in concentration of the toxin in the water. A more quantitative approach involving numerical modeling of toxin loading into the aqueous system originally was undertaken. However, given the currently available analytical tools and the breadth of the Plan Area, this approach was unable to capture the factors that result in the toxin becoming more available to the food chain, or in some cases the environmental/chemical factors that result in transformation of a chemical to a form that is more toxic in the ecosystem. For example, conversion of mercury in soils to methylmercury, a much more toxic and bioavailable form, will occur in restoration areas during the first inundations. Because there are insufficient data on soil mercury concentrations and the rate of transformation (which is determined by length of inundation, drying out of soils, and how often inundation occurs), the factors that will result in methylmercury availability to the food chain can be qualitatively discussed, but the resulting concentrations in the different restored marshes and floodplains cannot be quantified.

Bioaccumulation models that link the concentration of a toxin in the water to resultant concentrations in fish tissues for selenium and methylmercury have been developed and will be presented in the EIS/EIR (reference—CH2MHill). These models are useful for analysis, but given the uncertainty associated with the input parameters, particularly the Kd factor that estimates the transformation to a more bioavailable form, these results should be considered in the context of a full *qualitative* analysis. Review of bioaccumulation model results for mercury and selenium correspond well with the qualitative discussion and conclusions presented in this appendix. These results will be referenced here as appropriate, and a full explanation of computation is available in the EIR/EIS.

For reference, the EPA Ambient Water Quality Criteria for chronic exposures (AWQC-Fresh Water-Chronic) are included in the discussions of each toxin for context. The AWQC-Fresh Water-Chronic is expressed as the highest concentration of a substance in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Presented below is a qualitative evaluation that integrates the varied sources of toxins to the Delta, the biogeochemistry that determines how these toxins partition in the aqueous system (to sediment, water, or biota), how they are taken into the foodweb, and the potential effects on the covered fish species. This approach captures a much fuller picture of toxic presence and effects than possible with a quantitative approach.

D.4.1 Problem Formulation

Historical and current land use in the Bay-Delta has resulted in the release of potentially toxic constituents into the Bay-Delta environment. The effects of toxic constituents on the Delta ecosystem have been identified as contributing to the POD described by Baxter (2010). Preliminary proposal actions may serve to increase or decrease the presence and effects of the toxic constituents already present in the Delta and are deserving of attention in this effects analysis.

Several chemical-specific, environmental, and species-specific factors contribute to determining whether a constituent will cause toxic effects on biota. The general conceptual model outlined below is intended to evaluate these factors and to provide a full description of the potential for each toxin to affect covered species under the preliminary proposal actions.

D.4.2 Conceptual Model

The conceptual model for analyzing the ways that preliminary proposal actions could potentially change the level of effects of toxic constituents in the Bay-Delta on covered species is presented graphically in Figure D-1 and described further below.

The textual explanations in the following sections are meant to provide definitions of factors included in the conceptual model shown in Figure D-1, and information on how the factors work together to determine the ultimate effects on covered species. The conceptual model is meant to summarize and synthesize a complex system that integrates chemical-specific biogeochemistry with site-specific environmental factors and species/life stage–specific physiology.

D.4.2.1 Conceptual Model Components—Toxin Biogeochemistry

The toxins identified in the Delta environment, and the fate and transport of these chemicals, along with the propensity for these chemicals to enter the food chain are evaluated following the steps outlined below.

D.4.2.1.1 Contaminant Fate and Transport

The conceptual model for toxins includes a discussion of the biogeochemistry of the chemical and the fate and transport characteristics. The analysis of contaminant fate and transport involves identifying the source of the contaminant in the Delta, how the contaminant is transported and accumulates within the ecosystem, and the chemical properties of the contaminant that cause it to partition to sediment/water/air/biota. This analysis integrates the environmental setting and hydrology to determine how and where the contaminant is transported from its source area to other parts of the Delta.

The basic chemical characteristics that determine how a contaminant is transported and partitions in the environment include solubility in water, tendency to sorb to particulates, and volatility (tendency to occur as a vapor). A contaminant with high water-solubility (referred to as *hydrophilic*) can migrate dissolved in rivers. Alternatively, metals and some pesticides often have low solubility in water (referred to as hydrophobic) and tend to sorb to particulates and organic carbon, so they typically are found in sediments closer to the source.

Chemicals can be broken down in the environment by chemical or biological processes. The rate of this degradation is measured by a chemical-specific half-life, which is the time it takes for half of the mass to break down. Chemical degradation includes photodegradation, where the contaminant is chemically broken down by sunlight. Biological degradation is usually a product of bacterial degradation of organic chemicals.

Water chemistry also affects the fate, transport, partitioning and bioavailability of a contaminant in an aqueous system. Salinity, hardness, temperature, pH, organic carbon, and redox potential (in sediments) influence the form that a chemical will take. In many cases, certain forms of a given contaminant (species or ionic state) determine partitioning and the ultimate toxicity. For example, copper is more toxic in the cupric species (2+), than in the cuprous species (1+).

D.4.2.1.2 Bioavailability, Bioaccumulation

Bioavailability is a measure of the ability of a toxic to cross the cellular membrane of an organism, to become incorporated in that organism, and to enter the food chain (Semple 2004). Not all toxins are in a form that can be taken up by an organism. Bioavailability is not only chemical-specific, it can be specific to the chemical form that a constituent takes. For instance, copper in the 2+ state is more bioavailable than copper in the 1+ state, making the first form much more toxic than the second. Mercury in an organic complex as methylmercury is much more bioavailable and toxic than elemental mercury or mercury complexed with an inorganic compound.

In addition to the availability of the chemical to be taken up by biota, some chemicals are magnified more through the food chain. Bioaccumulation refers to accumulation of a chemical in tissues of an organism.

Bioaccumulation often is used interchangeably with the term *biomagnification*, referring to the increase in concentrations of a given chemical in biota as it moves through the food chain to the upper predator level. A common example of bioaccumulation and biomagnification is mercury in the tissues of game fish, such as tuna. For purposes of this analysis, the term *bioaccumulation* will encompass biomagnification through the food chain.

Bioaccumulation is a function of the chemical's specific characteristics and the way that the organism metabolizes the chemical—such as whether it is metabolized and excreted, or stored in fat. Toxins that are bioavailable and lipophilic (tend to accumulate in fatty tissue of an organism and are not very water soluble) typically bioaccumulate at higher rates. If stored, the chemical can bioaccumulate in the food chain, such as mercury and pesticides.

D.4.2.2 Conceptual Model Components—Effects of Preliminary Proposal Actions on Toxins

For the purposes of this analysis, the preliminary proposal conservation measures are grouped as either water operations or restoration, as depicted on Figure D-1. The mercury mitigation conservation measure also will be discussed within the restoration actions.

The greatest potential for effects on toxins related to the preliminary proposal water operations is the potential for changes in dilution and mixing of existing contaminants in the Delta. For instance, certain toxic contaminants, such as selenium, are known to be present in the San Joaquin watershed. A change in the proportion of San Joaquin water inputs to the Delta relative to the Sacramento River could result in diminished dilution (and increased concentrations) in the Delta of toxic contaminants from the San Joaquin watershed. Reduction of flows in the Sacramento River downstream of north Delta intakes also could result in decreased dilution of toxins in the river

The primary concern with the preliminary proposal habitat restoration measures regarding toxins is the potential for mobilizing contaminants sequestered in sediments of the newly inundated floodplains and marshes. This appendix provides an overview of what toxic contaminants are known to be present in these areas and the biogeochemical behaviors that will determine whether they could be mobilized into the aquatic environment and the food chain by restoration actions.

D.4.2.3 Conceptual Model Components—Effects of Changes in Toxins on Covered Species

The previous steps determine whether preliminary proposal actions potentially could change the amounts and bioavailability of toxins and where. This step looks at how these changes could affect covered species. The toxic effects of a chemical are determined by how it works on a biochemical level. Some of the types of effects are listed in Figure D-1 under the Toxic Effects step. Toxins can target specific tissues, organs, or organ systems. For example, toxins that affect the neurological, immune, or endocrine systems typically lead to potential effects on behavior, ability to combat disease, and reproduction. Certain toxins tend to accumulate in particular tissues or organs, such as the fatty tissues, liver, or kidneys; those that accumulate in fatty tissues have a greater potential to bioaccumulate. These factors determine the overall effect of the toxin on the organism and the ecosystem, and whether it will affect reproductive, developmental, or adult life stages. Effects of a particular toxic chemical can vary between species, and also between life stages within a species. The conceptual model for this effects analysis considers all these factors.

D.5 Results—Effects of Preliminary Proposal Conservation Measures on Toxins

D.5.1 Mercury

D.5.1.1 Mercury—Location, Environmental Fate, and Transport

Mining operations in the mountains drained by Central Valley tributaries resulted in transport and widespread deposition of mercury into the water and sediments of the Bay-Delta ecosystem.

Mercury, in the form of the mineral cinnabar, was mined mainly from the Coastal Range. In the Sierra Nevada and Klamath-Trinity Mountains, mercury was used for gold recovery in placer and hard-rock mining operations (Alpers and Hunerlach 2000; Alpers et al. 2005). Inorganic mercury was transported with sediment loads by creeks and rivers draining the mountains and became distributed throughout the riverbed, marsh, wetland, and floodplain sediments of the Delta, with highest concentrations in upper tributaries.

The Sacramento River is the primary transport route of methyl mercury to the Delta, and contributes about 80% of riverborne mercury inputs (Stephenson 2007; Wood 2010). The amounts of methylmercury will roughly correspond with these percentages. In the Sacramento River watershed, the highest concentrations of mercury are found in the Yolo Bypass and Cache Creek. Cache Creek, which drains a former mining area, is the largest contributor of mercury to the Delta, as it drains 2% of the area in the Central Valley and contributes 54% of the mercury (Foe 2008). Methylmercury concentrations decrease significantly (by 30% to 60%) downstream of Rio Vista, where concentrations were at or below 0.05 nanograms per liter (ng/l) (Foe 2003; Woods 2010). The Delta is listed on the Clean Water Act Section 303(d) list as an impaired water body for mercury in fish tissues. (SWRCB 2007).

For reference, the current Criterion Continuous Concentration (AWQC-Fresh Water-Chronic) for mercury in fresh water is 0.77 μg/L (770 ng/l). The criteria can be applied to total mercury, but it is derived from data for inorganic mercury (III) and therefore should be considered under protective if a substantial portion of mercury occurs as methylmercury. The total maximum daily loads (TMDLs) for methylmercury in the Delta and in San Francisco Bay also are provided below in Table D-3. The TMDL for the Delta is in process.

Table D-3. Mercury and Methylmercury Total Maximum Daily Loads (TMDLs) in the Delta and San Francisco Bay

Analyte	CTR[a]	USEPA Recommended Criteria[b]	Delta Methylmercury TMDL[c]	San Francisco Bay Mercury TMDL[d]
Mercury (ng/L)	50	770	—	25
Methylmercury (ng/L)	—	—	0.06	—

[a] Criterion for the protection of human health from total recoverable mercury in fresh water (USEPA 2006c).
[b] Criterion for the protection of chronic exposure from total mercury to freshwater aquatic life (USEPA 2006c).
[c] The recommended water column TMDL concentration of methylmercury for the protection of fish bioaccumulation (CVRWQCB 2008a).
[d] The recommended water column 4-day average TMDL concentration for total mercury (USEPA 2006c).

Relative to the Sacramento River, the San Joaquin River is a relatively minor contributor of methylmercury to the Delta. In the San Joaquin watershed, the Mokelumne-Cosumnes River is the greatest contributor of mercury, accounting for 2.1% of the total methylmercury in the Delta, with an average concentration of 0.17 ng/l (Woods 2010). Marsh Creek, which drains the Mt. Diablo mining area, contributes a small percentage (0.04%) because of its size, but it does have relatively high average concentrations of methylmercury estimated at 0.25 ng/l (Woods 2010). Bear Creek and Mosher Creek, which drain a former mining area, are also high in mercury, with concentrations

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reported at 0.31 ng/l (Woods 2010). These creeks are also small and contribute a relatively small percentage to the overall mercury budget in the Delta.

The chemistry of mercury in the environment is complex (Figure D-2). Elemental mercury and mercury in the form of inorganic compounds have relatively low water solubility and tend to accumulate in soils and sediments. When mercury forms an organic complex called monomethylmercury (commonly referred to as methylmercury) it becomes more water soluble and the toxicity and bioavailability are greatly enhanced, making it a primary concern for ecosystem effects. The toxicity of methylmercury is amplified as it bioaccumulates through the foodweb. Because of the widespread presence of toxic methylmercury in the Bay-Delta, much recent research has been completed on the cycling of methylmercury through the physical environment and biota of the area. The biogeochemistry of mercury in an aqueous system is illustrated on Figure D-2.

Conversion of inorganic mercury to methylmercury occurs in flooded fine sediments subjected to periodic drying-out periods and is associated with anaerobic (oxygen-depleted), reducing environments (Alpers et al. 2008). Methylmercury production is highest in high marshes that are subjected to wet and dry periods over the highest monthly tidal cycles; production appears to be lower in low marshes that are always inundated and not subject to dry periods (Alpers et al. 2008). Numerous other factors affect methylation of mercury in estuarine environments in addition to inundation regime; they include vegetation, grain size, pH, availability of binding constituents (iron, sulfur, organic matter), and factors influencing success of the microbes responsible for the methylation process (nutrients and dissolved oxygen) (Alpers et al. 2008; Wood et al. 2010).

In-situ production of methylmercury in Delta sediments is an important source of this toxin to the Delta ecosystem. Several investigators have calculated inputs of methylmercury to the Delta from sediments, with varying results (Stephenson 2007; Byington 2007; Foe 2008; Wood et al. 2010). Results of the CALFED Mercury Project Annual Report for 2007 (Stephenson 2007) indicate that river inputs (11.5 g/day methylmercury) and in-situ production from wetland/marsh sediments (11.3 g/day methylmercury) are the leading sources of methylmercury to the Bay-Delta waters, and have roughly comparable levels of input. Wood (2010) estimates that in-situ methylmercury production in open water and wetlands contributes approximately 36% of the overall methylmercury load to the Delta (approximately 5 g/day), but is less than riverine/tributary inputs (8 g/day). The higher estimate of methylmercury production from sediments reported by Stephenson is based on periods of higher water (wet), and may be more representative of what might occur when new ROAs are opened for inundation, especially when combined with the effects of sea level rise.

Photodegradation has been identified as an important factor that removes methylmercury from the Delta ecosystem. In the methylmercury budgets developed by Woods (2010), Foe (2008), Byington (2007), and Stephenson (2007), photodegradation rates are higher than sediment production rates for methylmercury. Gill (2008) identified photodegradation of methylmercury as potentially the most effective mercury detoxification mechanism in the Delta.

Specific photo-degradation rates vary on daily and monthly timescales, as the process is dependent on light intensity (Gill 2008). Photodegradation of methylmercury occurs in the photic zone of the water column (the depth of water within which natural light penetrates) and as such can be expected to occur in a large portion of the shallow, newly inundated ROAs. At the 1% light level, the mean depth for the photic zone in the Delta was calculated to be 2.6 meters, with measured depths ranging from 1.9 meters to 3.6 meters (Gill 2008; Byington 2007). Gill and Byington also conclude that photodegradation may be most active within the top half-meter of the water column in the Delta.

Mediated by sunlight, photodegradation occurs at higher levels in the dry season than in the wet season, with minimum photodegradation rates occurring December through February and maximum degradation rates occurring in May and June. (Byington 2007) Research by Byington indicates that photodegradation of methylmercury in marshes and tules in the Delta is severely diminished by reduced light penetration resulting from the presence of high dissolved organic carbon, turbidity, and aquatic vegetation.

Atmospheric deposition also may contribute to the mercury load; however, estimated daily loads are an order of magnitude lower than most other sources to the Delta and constitute approximately 1% of the entire methylmercury load contributed from external and within-Delta sources (Wood et al. 2010). In addition, atmospheric contributions are not anticipated to be altered by preliminary proposal actions. Therefore, atmospheric deposition can be considered an insignificant source from the perspective of assessing preliminary proposal effects.

D.5.1.2 Mercury—Effects of Preliminary Proposal Conservation Measures

D.5.1.2.1 Water Operations

The highest concentrations of methylmercury are in the Yolo Bypass and Cache Creek area. Mercury tends to accumulate in soils but is mobilized more readily into the food chain in an aqueous system, Operation of north Delta intakes will result in two hydrologic changes that could cause increased mobilization of mercury into the food chain. Yolo Bypass will have increased flows under preliminary proposal actions, which likely will increase mobilization of mercury present in soils. Also, Sacramento River reduced flow downstream of the north Delta intakes will diminish capacity of the river to dilute mercury flowing from the Yolo Bypass. Quantification of this effect on methylmercury in the aqueous system is not possible given the lack of information on current concentrations and distribution of mercury throughout the Yolo Bypass system, residence times of preliminary proposal–related inundation of Yolo Bypass, the rate of methylmercury production, and transport out of the Yolo Bypass and into the Sacramento River.

D.5.1.2.2 Restoration

As discussed above, in-situ conversion of mercury to methylmercury occurs at highest rates in intermittently flooded marshes and floodplains. Preliminary proposal restoration actions (CM 4) will expand intermittently wetted areas by converting agricultural and other upland areas to tidal, open water, and floodplain habitats, resulting in new areas with the potential to create a new source of methylmercury to the aquatic system.

Because the restoration areas will be inundated over wide areas, photodegradation may be enhanced. Recent research has indicated that photodegradation of methylmercury in shallow waters can remove a similar amount of methylmercury as that produced in sediments of the Delta system. Photodegradation has high potential to remove a percentage of the methylmercury produced in newly restored areas, with the rates partially dependent on the turbidity of the water column and the resultant depth of the photic zone. However, for purposes of this analysis, it is assumed that some amount of methylmercury production and mobilization in the vicinity of ROAs with the highest methylmercury concentration, specifically Cache Creek, Yolo Bypass and the Cosumnes and Mokelumne River confluence in the Sacramento River watershed, would occur. In summary, preliminary proposal restoration actions are likely to result in increased production and mobilization of methylmercury in the Delta, and increased bioavailability and toxicity of mercury due to transformation to a methylated form. Highest concentrations are expected in the first flushes of inundation of the ROAs closest to the locations listed above.

As part of the preliminary proposal, measures are being developed to mitigate the production of methylmercury in ROAs. These measures may include construction and grading that minimizes exposure of mercury-containing soils to the water column, design to support photodegradation, and pre-design field studies to identify depositional areas where mercury accumulation is most likely and characterization and/or design that avoids these areas. In addition, a TMDL for methylmercury is under development and would be integrated into the overall preliminary proposal.

D.5.1.2.3 Modeling Results—Mercury

Modeling performed as part of the EIR/EIS showed no appreciable changes due to the preliminary proposal conservation measures in mercury concentrations in water at modeled locations or in fish tissues. However, as discussed previously, quantitative modeling cannot account for all the variables determining mobilization and the bioavailability of mercury and other toxins in an aquatic system, and should be considered in the context of this qualitative analysis. For example the model does not account for transformation of mercury to methylmercury in newly inundated restoration areas.

Placeholder for final model results. Above text is based on preliminary results.

D.5.2 Selenium

D.5.2.1 Selenium—Location, Environmental Fate, and Transport

Selenium has been identified as an important toxin in the Bay-Delta, especially in the San Joaquin watershed where irrigation water historically has been recycled, resulting in greatly increased concentration of selenium in soils. Developmental effects on fish from selenium are well documented; locally, significant ecosystem effects were described in the early 1980s from water management practices that concentrated selenium at the Kesterson Reservoir in California. The fate and transport section below provides an overview of selenium sources in the Delta, and the biogeochemical processes that result in increased bioavailability of selenium in an aqueous system. The discussion is focused on the San Joaquin watershed and how selenium could be mobilized by preliminary proposal actions.

Selenium is a naturally occurring micro-nutrient that can have significant ecological effects at elevated concentrations. Elevated selenium levels are present in the Delta ecosystem, primarily due to mobilization of naturally occurring selenium by agriculture-related irrigation practices in the San Joaquin River basin. The marine sedimentary rocks of the Coast Ranges are particularly high in selenium and salts, as are the soils and sediments derived from these rocks and transported to the riverbeds, floodplains, and marshes of the Delta. Irrigation of soils derived from the marine sediments leaches the selenium and salts, and the subsequent practice by farmers to drain excess shallow groundwater from the root zone to protect their crops results in elevated concentrations of selenium in groundwater and receiving rivers (McCarthy and Grober 2001). In the San Joaquin watershed in particular, the practice of reusing irrigation water has resulted in even more concentration of selenium in soils.

Selenium concentrations in the Delta are highest in the Grassland watershed of the San Joaquin River, and specifically a 97,000-acre area within this watershed referred to as the Drainage Project Area shown in Figure D-3. This area was identified as a major contributor of selenium to the Delta and accounted for 88% of the selenium in the lower San Joaquin River. The mean annual selenium concentration of water discharging from the Drainage Project Area was 68 micrograms per liter (μg/l) between 1986 and 1988 (CVRWQCB 2001—selenium TMDL for the San Joaquin). However, mitigation measures more recently have been put into place to manage selenium discharges to meet a requirement of 5μg/l concentration between Sack Dam and the Merced River, as described in the following paragraph.

For reference, the current AWQC-Fresh Water-Chronic for selenium in fresh water is 5.0 μg/L and is expressed as the total recoverable metal in the water column. Table D-4 below provides other available benchmarks.

Table D-4. Applicable Federal Criteria, State Standards/Objectives, and Other Relevant Effects Thresholds for Selenium

	Region 5 Basin Plan[a]	Region 2 Basin Plan[b]	CTR[c]	Drinking Water MCL[d]	USEPA Recommended Criteria[e]	Other Relevant Thresholds[f]
Selenium (μg/L)	5/12	5/20	5/20	50	5/variable	2

[a] Objectives apply to the lower San Joaquin River from the mouth of the Merced River to Vernalis as 5 μg/L (4-day average) and 12 μg/L (maximum concentration) total selenium concentration (CVRWQCB 2009a).

[b] Selenium criteria were promulgated as total recoverable concentrations for all San Francisco Bay/Delta waters in the National Toxics Rule (NTR) (USEPA 1992; SFBRWQCB 2007).

[c] Standard is Criterion Continuous Concentration as 5 μg/L total recoverable selenium; CTR deferred to the NTR for San Francisco Bay/Delta waters and San Joaquin River (USEPA 2000).

[d] In addition, the California Office of Environmental Health Hazard Assessment (OEHHA 2010) has recommended a Public Health Goal of 30 μg/L.

[e] Criteria for protection of freshwater aquatic life are 5 μg/L (continuous concentration, 4-day average) total recoverable selenium and they vary for the Criterion Maximum Concentration (CMC; 24-hour average) (USEPA 2010). The CMC = 1/[(f1/CMC1) + (f2/CMC2)] where f1 and f2 are the fractions of total selenium that are treated as selenite and selenate, respectively.

[f] Concentration as total recoverable selenium identified as a Level of Concern for the Grassland Bypass Project (Beckon et al. 2008).

Under the Grassland Bypass Project, selenium discharges to Mud Slough (in the San Joaquin watershed) must be reduced to 5 μg/l (4-day average) by December 31, 2019. Further, the CVRWQCB recently approved an amendment to the basin plan in light of this project (CVRWQCB 2010a). The amendment requires that agricultural drainage be halted after December 31, 2019, unless water quality objectives are met in Mud Slough (north), and the San Joaquin River between Mud Slough (north) and the mouth of the Merced River (CVRWQCB 2010a). Also, if the State Water Board finds that timely and adequate mitigation is not being implemented, it can prohibit discharge any time prior to December 31, 2019 (CVRWQCB 2010a). As a result, a substantial reduction in selenium inputs (unrelated to the preliminary proposal) to the San Joaquin River by 2019 would be expected to result in lower selenium inputs to the Delta from the San Joaquin River.

According to the Grasslands Project Report for 2006–2007 selenium loads had already been reduced by 75% in 2007 relative to 1996 levels (San Francisco Estuary Institute for the Oversight of the Grasslands Project Subcommittee—Chapter 1, 2006–2007). Concentrations of selenium in tributaries and channels exceeded 5 µg/L during the 2006–2007 monitoring period, so water quality is not yet meeting the final goal. However, selenium concentrations measured in the San Joaquin River were consistently below 5 µg/L (San Francisco Estuary Institute for the Oversight of the Grasslands Project Subcommittee—Chapter, 2006–2007). As selenium discharge from the Grasslands continues to decrease as the 5µg/L goal is approached, concentrations in the San Joaquin also can be expected to decrease.

The Sacramento River is not considered a significant source of selenium to the Delta. Selenium concentrations in the Sacramento River at Freeport are consistently and comparatively low, averaging 0.06 ± 0.02 µg/l (Cutter and San Diego–McGlone 1990 as referenced in the Reclamation BO on the CVP). Thus, the total load of selenium contributed by the Sacramento River to the Delta is dependent on the flow rate.

Elevated selenium concentrations also have been identified in Suisun Bay. Although particulate concentrations of selenium in this region are considered low, typically between 0.5 and 1.5µg/g (Stewart 2004), the bivalve *C. amurensis* contains elevated levels of selenium that range from 5 to 20 µg/g. Given the fact that *C. amurensis* may occur in abundances of up to 50,000 per m2, this area can be considered a sink for selenium because 95% of the biota in some areas are made up of this clam.

Selenium can occur in four oxidation stages as selenates (Se+6), selenites (Se+4), selenides (Se-2), or elemental selenium. The oxidized state, selenates (Se+6), is soluble, and the predominant species in alkaline surface waters and oxidizing soil conditions. Selenates are readily reduced to selenites (Se+4) and selenides (Se-2), which are more bioavailable than selenate. Further reduction to elemental selenium can result in an insoluble precipitate, which is not bioavailable.

Although selenium is soluble in an oxidized state, the majority typically becomes reduced and partitions into the sediment/particulate phases in an aqueous system; these reduced sediment/particulate phases are the most bioavailable. Selenium in soils is taken up by plant roots and microbes and enters the food chain through uptake by lower organisms. A portion of the selenium also is recycled into sediments as biological detritus. Lemly and Smith (1987) indicate that up to 90% of the total selenium in an aquatic system may be in the upper few centimeters of sediment and overlying detritus (Lemly 1998).

Oxidized forms of selenium (selenates and selenites) may reduce further to precipitate as elemental selenium or complex with particulates. Selenate reduces to elemental selenium through dissimilatory reduction through reactions with bacteria. These reactions reduce selenium from surface waters resulting in an increase in selenium concentrations in sediment over time. In wetlands in particular, the organic-rich stagnant waters create a chemically reducing environment in which dissolved selenate is able to convert to selenite or elemental selenium(Werner et al. 2008). The longer the residence time of surface waters, the higher the particulate concentration resulting in higher selenium concentrations in wetlands and shallows. (Presser and Luoma 2006). Aquatic systems in shallow, slow-moving water with low flushing rates are thought to accumulate selenium most efficiently (Presser and Luoma 2006; Lemly 1998).

Bioaccumulation can be an important component of selenium toxicity. Selenium enters the food chain at a low trophic level and under certain conditions, is magnified up the food chain. Lower trophic organisms can bioaccumulate hundreds of times the waterborne concentration of selenium.

However, research has demonstrated that when the food chain is based on plankton rather than sessile filter feeders, plankton will excrete the majority of the selenium, and selenium will not be bioaccumulated at higher trophic levels (Stewart 2004). This is an important factor that mitigates bioaccumulation in some of the preliminary proposal covered species, and is more fully discussed in later sections of this appendix.

D.5.2.2 Selenium—Effects of Preliminary Proposal Conservation Measures

Modeling performed as part of the EIR/EIS showed no appreciable changes in selenium concentrations in water at modeled locations or in fish tissues due to preliminary proposal conservation measures. However, as discussed previously, quantitative modeling cannot account for all the variables determining mobilization and the bioavailability of selenium and other toxics in an aquatic system, and should be considered in the context of this qualitative analysis.

D.5.2.2.1 Water Operations

Because the San Joaquin River historically has been a major contributor of selenium to the Bay-Delta system, there is a concern that the increased contribution to the Delta from the San Joaquin River relative to the Sacramento River as a result of preliminary proposal operations would result in an increase in selenium transport and deposition in the Delta. However, if the water quality objective outlined in the proposed basin plan amendments (CVRWQCB 2010b) for selenium of 5 μg/l (4-day average) is met, this would represent a 72% decrease in selenium loads to the San Joaquin River. In fact, selenium concentrations in the San Joaquin River downstream of Grasslands were consistently below 5 μg/l, while drainage in the Grasslands Project Area was still very high (up to 50 μg/l at Mud Slough). The concentrations of loading from the Grasslands Project Area and resultant concentrations in the San Joaquin River are expected to continue to decline and will greatly diminish the source of selenium to the San Joaquin River and the Delta as a whole.

Concentrations of selenium in the Sacramento River system are considered low, with the total amount of selenium transported dependent on the volume of flow. Decreased Sacramento River flows into the Delta as a result of the preliminary proposal are expected to result in minimal effects on selenium water concentrations in the Delta.

The decrease in selenium discharges from the Grasslands watershed, which historically has been the primary source of selenium to the Delta and to the San Joaquin River, will temper the effects of increased San Joaquin inflow to the Delta, with decreased dilution from the Sacramento River under the preliminary proposal.

D.5.2.2.2 Restoration

Selenium sequestered in sediments has the potential to be mobilized and become bioavailable in an aquatic environment. In the Bay Delta, and especially in the San Joaquin watershed, selenium has been concentrated in agricultural lands. Inundation of these areas through restoration of marshes and floodplains will lead to mobilization of sequestered selenium and increase exposures to the food chain. The rate at which selenium will become mobilized as part of restoration will depend on the amount of selenium stored in the sediments, the length of inundation, and whether sufficient time allows the selenium to cycle through the aquatic system and into the food chain. It is likely that the highest concentrations of selenium will be mobilized during the initial flooding, but will taper off with time; the length of time for the majority of selenium to flush out is not currently known. Given that the San Joaquin River historically has delivered selenium to the Delta, the south Delta ROAs have the most potential for mobilization of selenium

In the long term, selenium inputs to the Delta should decrease by restoring agricultural lands to marsh habitat; selenium would no longer be concentrated by irrigation of these formerly farmed areas. This is especially true of the south Delta, where the concentrated selenium will be flushed through, but additional concentration from irrigation will cease. In contrast to the benefit of stopping application of pesticides to restored farmland, the benefit associated with selenium likely will be low, as selenium actually is leached out of the soils by agricultural use rather than applied.

D.5.2.2.3 Modeling Results— Selenium

Modeling performed as part of the EIR/EIS showed no appreciable changes due to the preliminary proposal conservation measures in selenium concentrations in water at modeled locations or in fish tissues. However, as discussed previously, quantitative modeling cannot account for all the variables determining mobilization and the bioavailability of mercury and other toxics in an aquatic system and should be considered in the context of this qualitative analysis. For example, the model does not account for the difference in bioaccumulation between a clam-based diet and a plankton-based diet, which has significant effects on resultant selenium transfer through the food chain.

Placeholder for final model results. Above text is based on preliminary results.

D.5.3 Copper

D.5.3.1 Copper—Location, Environmental Fate, and Transport

In the Delta, anthropogenic sources of copper include pesticides/herbicides, mine drainage, and anti-foulants (such as paint used on boat bottoms) (USEPA 2009). As agriculture is the dominant land use in the Delta, use of pesticides/herbicides is a dominant source of copper to the environment. Mine drainage also has been a historical source of copper to the Delta. The Iron Mountain Mines Superfund Site, a former mine that released acid mine drainage to the Sacramento River upstream of Keswick Dam, has been a significant source of copper and other metal contamination. However, the Superfund Site is undergoing remediation that has decreased discharge of copper into the rivers, and a TMDL has been implemented (CVRWQCB 2002). Following remediation, copper inputs from this mine should continue to decrease.

Copper (Cu) is a naturally occurring element that is present in water, air, and many soils in the environment. It is an essential trace element required by many plants and animals at low concentrations but can be toxic at elevated concentrations. In a non-aqueous environment, copper will tend to adhere to soils and is relatively immobile. In an aqueous system, copper is considered one of the more mobile heavy metals. It partitions between sediment and particulates, and as particulates, it is taken up by low trophic levels or complexes with organics or inorganics in the water column. Typically it will occur in one of two oxidation states, cuprous ion (Cu^{1+}) and cupric ion (Cu^{2+}) (USEPA 2009). Toxicity is much higher for the Cu^{2+} ion, compared to the Cu^{1+} ion and the copper that is organically complexed (Buck et al. 2007; Manahan and Smith 1973; Sunda and Guillard 1976).

Overall, levels of copper in the Delta ecosystem do not appear to be significantly elevated. Copper concentrations in the Sacramento River have been reported to be consistently low, with some seasonal fluctuation (Connon 2010; Domagalski 2008). Dissolved copper concentrations in the Sacramento River at Freeport were reported at approximately 2 µg/l by Domagalski (1998). Higher copper concentrations have been reported in tributaries to the Sacramento River, in proximity to agricultural areas. Concentrations over 6 µg/l were reported in Arcade Creek (Domagalski 1998).

The current AWQC-Fresh Water-Chronic for copper in fresh water is derived on a site-specific requiring the input of 10 separate site-specific parameters to calculate the criteria including temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. Because of the lack of comprehensive data for these parameters throughout the Bay-Delta, it was not possible to calculate an AWQC-Fresh Water-Chronic for copper.

Bruns (1998) conducted water sampling between 1993 and 1995, compared both dissolved and total copper results against EPA AWQC and other criteria, and reported concentrations below criteria from almost all locations, including the Sacramento River. Because the criteria are dependent on sample-specific water quality measurements (including hardness), the criteria varied between sampling episodes. Significantly higher copper levels (at least an order of magnitude higher than all other results) that exceeded criteria, were reported for Prospect Slough at the head of the Yolo Bypass; however it should be noted that the high Prospect Slough data were for total rather than dissolved copper concentrations. Dissolved copper concentrations for Prospect Slough were not available for these elevated samples.

Together the copper data sets discussed above indicate low levels of copper (less than 2µg/l) throughout the Delta waterways and elevated concentrations in agricultural drainage sloughs, and at the head of Yolo Bypass, where mining discharges of copper may have accumulated.

D.5.3.2 Copper—Effects of Preliminary Proposal Conservation Measures

D.5.3.2.1 Water Operations

Overall, preliminary proposal water operations are not expected to have much effect on copper distribution in the Delta aquatic system, mainly because copper is dispersed through the environment at elevated, but low concentrations. Under preliminary proposal water operations, the Sacramento River will have decreased flows below the north Delta intakes and may have diminished capacity to dilute toxins released through flushing of Yolo Bypass. Given that the highest concentrations of copper have been reported in Yolo Bypass, there is potential for increased copper concentrations in Yolo Bypass discharge during the first phases of inundation, which should decrease over time as the copper is flushed out of the soils. It is more likely that exposures to copper will increase under the preliminary proposal conservation measure for the Yolo Bypass, than preliminary proposal water operations.

D.5.3.2.2 Restoration

Mobilization of copper due to a combination of north Delta preliminary proposal water operations and restoration in the Yolo Bypass is discussed above. In addition, restoration of agricultural lands will have two outcomes relative to copper: copper contained in soils will be mobilized, and copper in pesticides that would have been applied to the agricultural land will be subtracted from the total Delta copper loads. As with the Yolo Bypass, mobilization of copper in other ROAs will be highest during the first inundations, as copper is flushed out of the soils and enters the aqueous system. Quantification is not possible given the current level of information on copper concentrations sequestered in sediments, or the residence time of inundation required to fully mobilize the copper. Restoration of agricultural land to marshes and floodplains will result in decreased application of copper containing pesticides and decreased copper loading to the Delta. This net benefit at least partially will counter the copper introduced to the aquatic system through mobilization during inundation. Overall, it is likely that some levels of copper will be mobilized and become bioavailable, especially during the first years of inundation of former farmlands.

D.5.4 Ammonia/um

D.5.4.1 Ammonia/um—Location, Environmental Fate, and Transport

Ammonia is present in water in two forms: as un-ionized ammonia (NH^{3+}), also sometimes referred to as *free ammonia*, and as a positively charged ammonium ion (NH^{4+}). These two forms are collectively referred to as *total ammonia* or *ammonia plus ammonium*. Generally, un-ionized ammonia is more toxic to fish while ammonium is taken up by plants and algae as a nutrient and can drive algae blooms and growth of invasive species (Jabush 2011).

The primary source of total ammonia in the Delta is effluent discharged from WWTPs (Jassby 2008). The contributing treatment facilities include the Sacramento Regional WWTP and the Stockton Regional Wastewater Control Facility. The Sacramento plant is the source of the largest wastewater effluent discharge to the Delta (Jassby 2008), contributing an average of 141 MGD and accounting for 1 to 2% of the river water volume (Foe et al. 2010). The facility is also the largest source of total ammonia discharge to the Delta, making up 90% of the Sacramento River ammonia load (Jassby 2008).The Stockton facility historically had been a source of the total ammonia load to the Delta via the San Joaquin River. This is no longer the case, as the Stockton facility has upgraded its treatment systems in recent years to include technology to remove ammonia and ammonium from effluent before discharge to the river (City of Stockton 2011).

During a monitoring program conducted in 2009 and 2010, water samples were collected on a monthly basis from 21 locations throughout the Delta, with a focus on tracking concentrations downstream of the Sacramento WWTP (Foe et al. 2010). Results of this study indicated:

- Ammonia concentrations were higher downstream (highest average 0.46 mg/l) of the Sacramento WWTP compared to upstream (average 0.04 mg /l).
- The highest ammonia concentrations were detected at Hood, located 7 miles downstream of the WWTP.
- Downstream of Hood, total ammonia concentrations dropped continuously to an average of 0.08 mg/l at Threemile Slough, located 20 miles downstream of the WWTP.

The EPA has developed criteria for total ammonia which requires site-specific inputs for temperature, pH, and the presence/absence of the Unionid mussel *Anadonata* spp., which is very sensitive to ammonia toxicity. None of the ammonia data collected for 344 samples over one year exceeded the USEPA chronic criterion for early life stages of fish present in the Delta (Foe et al. 2010). In lifecycle testing, Teh and coauthors (2011) reported that Delta copepods were affected by concentrations as low as 0.38 mg/l of total ammonia nitrogen.

An updated draft ambient water quality criteria (AWQC) (2009) for fresh water has been published but has not yet been adopted. If the new levels are adopted in the future, ammonia criteria would change significantly, and surface water in the Sacramento River well downstream of the Sacramento plant could exceed these new criteria.

The current National Pollutant Discharge Elimination System (NPDES) permit (2010) for the Sacramento WWTP contains both new and interim standards for ammonia. In order to comply with current standards (Table D–5), the Sacramento plant will need to install new systems similar to the Stockton plant to reduce ammonia concentrations in effluent. Compliance with new effluent limits will be required as of November 1, 2020, or once the new systems are in place, whichever occurs first (CVRWQCB 2010 NPDES). The Sacramento plant is pursuing ways to obtain revenue to support the upgrade (Sacramento Delta Solutions 2011).

Table D–5. Sacramento Wastewater Treatment Facility Effluent–National Pollution Discharge and Elimination System (NPDES) Permit Limits

	Units	Stockton (2008) Average Daily	Sacramento Effective 2010 (Interim) Average Daily	Sacramento Effective 2020 (New) Average Daily
Ammonia, total as N	mg/l	5	33	1.8
	lbs	2,294	49,400	2,720
Design flow	mgd	55	181	181
Source: CVRWQCB 2010 NPDES.				

D.5.4.2 Ammonia/um—Effects of Preliminary Proposal Conservation Measures

D.5.4.2.1 Water Operations

The main concern associated with the effects of preliminary proposal water operations on ammonia is that decreased flow in the Sacramento River could result in diminished capacity to dilute ammonia in Sacramento WWTP discharges.

Given the possible link established between ammonia from WWTPs and the POD (Dugdale et al. 2007; Wilderson et al. 2006), an increase in ammonia concentrations is of concern. Recent data (Foe et al. 2010) indicate that concentrations of ammonia downstream of the WWTP outfall do not currently exceed USEPA AWQC. These conditions are maintained with a current allowed ammonia concentration in WWTP effluent of 33 mg/l. By 2020, effluent must be below 1.8 mg/l ammonia, an 18-fold decrease in ammonia concentrations. It would take a similar decrease in Sacramento River flows to achieve the current conditions, which meet AWQC, and little to no effects are expected from preliminary proposal actions on ammonia/um.

D.5.4.2.2 Restoration

Restoration conservation measures will not affect distribution or levels of ammonia/um in the Delta.

D.5.5 Pyrethroids

D.5.5.1 Pyrethroids—Location, Environmental Fate, and Transport

Pyrethroids are a group of synthetic chemicals currently used as insecticides in urban and agricultural areas. More than 1,000 synthetic pyrethroids have been developed (ASTDR 2003), but only 25 are registered for use in California (Spurlock and Lee 2008). Pyrethroids are powerful neurotoxins, have immunosuppressive effects, and can inhibit ATPases (essential enzymes) (Werner and Orem 2008). Pyrethroids can cause acute toxicity at concentrations as low as 1 µg/l in fish and aquatic invertebrates (Werner and Orem 2008).

Overall pyrethroid use in the Delta has nearly quadrupled from 1990 to 2006 from approximately 27,000 kilograms per year (kg/yr) to over 101,000 kg/yr in 2006 (USDOI 2008) with five pyrethroids (lambda-cyhalothrin, permethrin, esfenvalerate, cypermethrin, and cyfluthrin) among the top agricultural insecticides in California (by acres treated) (Werner and Orem 2008). As land use in the Delta is predominantly agricultural (73% of land use), agricultural pyrethroid sources are expected to be significant. Significant sources of pyrethroids coming into the Delta from agricultural land include summer irrigation return flows from treated areas, winter stormwater runoff from orchards as a result of the common practice of applying pyrethroids during the winter season, and draining of excess surface water from rice fields during cultivation (Oros and Werner 2005).

Pyrethroids are hydrophobic, have low water solubility, low Henry's law constants, and high octanol-water partitioning coefficients; that is, they do not readily volatilize and have a tendency to bond to particulates and will not stray far from the source. Once pyrethroids enter the Delta, they are easily adsorbed to suspended particles, organic material, soil, and sediments and do not readily volatilize (Oros and Werner 2005). Because of the hydrophobic nature of pyrethroids, it is estimated that 94% of pyrethroids used in the Central Valley remain at the application site and approximately 6% degrade, with half life ranging from days to months, leaving only 0.11% ultimately available for transport through the Delta (Werner and Orem 2008). Analysis of 70 sediment samples from irrigation canals dominated by agricultural drainage in 10 counties in the Central Valley showed pyrethroids in 75% of the samples (Weston et al. 2004). However, pyrethroids were not often detected in agricultural drainage waters, demonstrating their strong affinity to sediments (Weston 2010). Weston (2010) also reported toxic levels of pyrethroids in Sacramento WWTP effluent.

Because of its behavior in the environment there is the possibility for multiple exposure pathways in the Delta aquatic system. Benthic organisms may be exposed to pyrethroids in sediment, and pelagic species are exposed to pyrethroids adsorbed to particulates in the water column. Because pyrethroids are lipophilic, they have a tendency to bioaccumulate through the food chain (Werner and Orem 2008).

Breakdown of pyrethroids can occur through both chemical and biological processes and can take from days to months depending on a number of factors (Werner and Orem 2008). Half-lives (the average time it takes for the concentration of the chemical to be reduced by one-half) of pyrethroids are influenced by temperature and pH. At an alkaline pH, some pyrethroids can degrade through hydrolysis; however, most are stable at the relatively neutral pH of Delta waters. (Werner and Oram 2008).

Many pyrethroids also are susceptible to degradation via sunlight, called photodegradation. The half life of different pyrethroids in water varies greatly with differences in their susceptibility to sunlight, from 0.67 days for cyfluthrin to 600 days for fenpropathrin (Werner and Oram 2008). High turbidity and the presence of plants can reduce UV-light penetrations and increase pyrethroid half life, allowing increased residence times and the potential for greater adsorption to sediment.

D.5.5.2 Pyrethroids—Effects of Preliminary Proposal Conservation Measures

D.5.5.2.1 Water Operations

Because of widespread use on agricultural land and the biogeochemistry of the chemicals, pyrethroids are contained in agricultural soils throughout the Delta. Because preliminary proposal water operations would not involve flooding of pyrethroid-containing soils, which could mobilize the chemicals, there are no expected effects on pyrethroids.

D.5.5.2.2 Restoration

As discussed above, pyrethroids have been applied widely to agricultural land across the Delta; they tend to stay sequestered in soils and will be present in ROA soils. Flooding of ROAs will make them available to the aquatic food chain through benthic or suspended particles in the water column. However, because pyrethroids have strong affinity for soils, they are unlikely to be transported very far from the source area, and exposures to biota will be localized but will magnify through the food chain as the lipophilic pyrethroids accumulate in higher trophic levels. Restoration likely will result in minimal increases in pyrethroids in the water column, and more of an effect on the biota. As is true for all the currently used pesticides, preliminary proposal cconservation measures involving restoration of agricultural lands to marshes and floodplains also will result in a decrease of pyrethroid use and loading to the ecosystem. A decrease in use will at least partially counter the mobilization of pyrethroids from inundation and will provide a long-term benefit to the ecosystem.

D.5.6 Organochlorine Pesticides

D.5.6.1 Organochlorine Pesticides—Environmental Fate and Transport

Organochlorine pesticides, specifically DDT, chlordanes, and dieldrin, are legacy pesticides that are no longer used but persist in the environment (Werner et al. 2008). These pesticides came into use from the late 1930s to the late 1940s and were phased out for general use in the 1970s; however, both chlordane and dieldrin remained in use until the late 1980s for termite control (Connor et al. 2007). The Sacramento and San Joaquin Rivers and the Delta are thought to be significant sources of organochlorine pesticides as the historical use of these compounds is primarily agricultural (Conner et al. 2007).

Organochlorine pesticides are very hydrophobic and are very persistent in the environment. DDT will degrade to DDD and DDE, but these toxic byproducts have very long half lives. Although organochlorine pesticides are no longer used as pesticides, they persist in the environment and continue to be present in soils and sediment. The CVRWQCB Agricultural Waiver Program recently reported detections of DDT and other organochlorines in Delta agricultural ditches and drainage channels (Werner et al. 2008). Because they do not dissolve in water, organochlorines enter the food chain in particulate form, mainly through uptake by benthic fauna. They are strongly lipophilic and biomagnify in higher trophic levels.

The current AWQC-Fresh Water-Chronics for the organochlorine pesticides of concern in the Bay-Delta, DDT, chlordane, and dieldrin, are 0.001, 0.0043, and 0.056 µg/L. It should be noted, however, that EPA has flagged two of these three criteria (chlordane and DDT), that the criteria are based on the Final Residual Value (FRV) procedure, and that the Agency anticipates that future revisions will not be based the FRV procedure.

The highest concentrations in sediments and the greatest loading of organochlorine pesticides are thought to come from the western tributaries of the San Joaquin River, and high concentrations have been reported in San Joaquin River sediments (Gilliom and Clifton 1990 cited in Domagalski 1998). However, total concentrations in the water column were low, consistent with the strong affinity of organophosphates for sediments. Given the persistence of organophosphates, and their broad historical use in agriculture prior to the 1970s, a more recent study involving collection and analysis of 70 sediment samples over 10 counties in the Central Valley showed that organophosphates continue to be present in sediments, and at high concentrations, especially in agricultural drainage canals (Weston et al. 2004). This study found DDT in almost all samples collected, with a median concentration of 6.9 ng/g, and a maximum concentration of 408 ng/g in a drainage canal. DDE and other organophosphates also were detected at high levels in drainage canal sediments.

D.5.6.2 Organochlorine Pesticides—Effects of Preliminary Proposal Conservation Measures

Organochlorine pesticides almost surely will be sequestered in the formerly agricultural soils within ROAs. The highest concentrations will be in the ditches, creeks, and drains that received agricultural discharges. Because these chemicals tend to stay in soils, exposures to the food web will be through benthic fauna and to particulates in the water column, which will settle out in low energy environments, such as marshes.

D.5.6.2.1 Water Operations

Preliminary proposal water operations will result in an increased ratio of San Joaquin River water mixing with Sacramento River inputs within the Delta. Although the highest organophosphate concentrations in sediments have been reported in the San Joaquin watershed, concentrations in water are low, and no changes in the load or concentrations of organophosphates transported into the Delta by the San Joaquin River are anticipated.

D.5.6.2.2 Restoration

Because of the long history of agriculture in the Delta and the persistence of organochlorine pesticides in sediments, ROAs likely will contain significant concentrations of organochlorine pesticides in sediments. Flooding of these areas is expected to mobilize some of the pesticides, although it is not possible to calculate the amounts because current levels of pesticides are unknown. Because these pesticides settle out of the water column in low-velocity flow, it is also likely that the pesticides would not be transported very far from the source area and would be deposited close to the ROA.

D.5.7 Organophosphate Pesticides

D.5.7.1 Organophosphate Pesticides—Environmental Fate and Transport

Organophosphate pesticides (organophosphates) are human-made chemicals that are used for pest control in both urban and agricultural environments. Sources of diazinon and chlorpyrifos in the Delta are predominantly agricultural as the sale of these compounds for most nonagricultural uses has been banned in recent years. In the Delta, diazinon is applied to crops during the dormant season (December–February) and irrigation or growing season (March–November) fairly equally; however, the majority of chlorpyrifos (97%) is applied to Delta crops during irrigation season (McClure et al. 2006).

Diazinon and chlorpyrifos have slightly different chemical properties that affect the way they behave in aquatic environments. Diazinon is fairly soluble and mobile and will bind only weakly to soil and sediment. Chlorpyrifos is less soluble than diazinon and less mobile and has a tendency to bind much more strongly to soil and sediment (Newport Bay TMDL). Consequently, diazinon enters the Delta dissolved in runoff, while chlorpyrifos enters the Delta adsorbed to soil particles (McClure et al. 2006). Unlike organochlorine pesticides, organophosphates do not tend to bioaccumulate, as they are readily metabolized by most organisms. For example, diazinon in fish will be approximately 96% removed in just 7 days (McClure et al. 2006).

Surface water data indicate that concentrations are high for both diazinon and chlorpyrifos in back sloughs and small upland drainages, and concentrations are lower in both the main channels and main inputs to the Delta. High concentrations of chlorpyrifos are also found in Delta island drains, but concentrations of diazinon remain low in the same drains (McClure et al. 2006). In the past, elevated concentrations of diazinon and chlorpyrifos also have been detected in the Sacramento and San Joaquin Rivers in the Delta during particularly wet springs and after winter storm events (McClure et al. 2006), suggesting that increased flow will result in increased mobilization of both diazinon and chlorpyrifos.

McClure and others 2006 summarize surface water data for diazinon from 1991 to 2005 and chlorpyrifos from 1988 to 2005 from a number of previous sampling programs and studies and compared results to the proposed maximum allowable hourly concentrations of 160 and 25 ng/l for diazinon and chlorpyrifos, respectively. Locations where diazinon exceeded 160 ng/l in more than 10% of samples included Mosher Slough, San Joaquin River near Stockton, Stockton Diverting Channel, and French Camp Slough. Likewise chlorpyrifos results showed more than 10% of samples collected at these locations exceeded 25 ng/l and included Ulatis Creek, Mosher Slough, Middle Roberts Island Drain, French Camp Slough, Paradise Cut, and Stockton Diverting Channel.

For context, the current AWQC-Fresh Water-Chronic for diazinon is 0.17 μg/L. There is no AWQC-Fresh Water-Chronic for chlorpyrifos.

D.5.7.2 Organophosphate Pesticides—Preliminary Proposal Conservation Measures

D.5.7.2.1 Water Operations

Because the organophosphates are distributed throughout the Delta, changes in hydrology and mixing in the Delta due to preliminary proposal water operations should not affect the distribution or mobilization of these chemicals.

D.5.7.2.2 Restoration

Organophosphate pesticides are present in ROA soils that would be inundated under preliminary proposal conservation measures. Because the solubility, tendency to adhere to soils and particulates, and degradation rates for these compounds vary, it is difficult to estimate the extent to which inundation would cause the contaminants to be mobilized and more bioavailable in the aquatic system. One would have to assume that there would be some level of increase of these contaminants in the aquatic system near ROAs during the first inundations.

D.5.8 Endocrine Disruptors

D.5.8.1 Endocrine Disruptors—Environmental Fate and Transport

Endocrine-disrupting compounds (EDCs) can interfere with the hormonal system in fish and act at extremely low (nanograms per liter) concentrations, resulting in negative effects on reproduction and development (Bennett et al. 2008; Riordan and Adam 2008; Lavada et al. 2009). Implications for Delta fish communities include changes in population distributions (e.g., changes in sex ratios that may affect population dynamics) that may be contributing to pelagic the POD (Brander and Cherr 2010).

Major sources of EDCs in the Central Valley are thought to be pyrethroid pesticides from urban runoff (Oros and Werner 2005; Weston and Lydy 2010), WWTPs (Routledge et al. 1998), and rangelands (Kolodziej and Sedlack 2007). EDCs also include steroid hormones (such as ethinylestradiol, 17β-estradiol, and estrone), plant constituents, plasticizers, and other industrial by-products. Pyrethroids have been documented to pass through secondary treatment systems at municipal wastewater treatment facilities at concentrations that are toxic to aquatic life, and still may be present in detectable concentrations following tertiary treatment (Weston and Lydy 2010). Confined animal feeding operations and grazing lands can contribute steroid hormones at concentrations high enough to feminize sensitive fish species. Runoff from manure-treated fields and rangelands where livestock have direct access to surface waters can result in introduction of excreted endogenous steroid hormones, including estrogens, androgens, and progestins (Kolodziez and Sedlack 2007). Cultivated fields may contribute naturally occurring estrogenic compounds, such as mycotoxins, and some agricultural pesticides and wetting agents (nonionic detergents) can be converted to estrogenic compounds in the environment or in the liver.

Estrogenic activity is a measurement of the effects of EDCs in the environment; however, this measure does not provide information on the causative substances. Documenting presence of multiple EDC compounds in surface waters does not necessarily indicate the constituent(s) responsible for adverse effects on fish populations. For example, Lavado et al. (2010) conducted a survey of surface waters from 16 locations in California, which were analyzed for EDCs using bioassays (which indicate levels of estradiol equivalents [EEQs]) and analysis for steroid hormones, detergent metabolites, agrichemicals, and other anthropogenic contaminants indicative of pharmaceuticals and personal care products. Samples from two of the 16 survey locations with estrogenic activity identified were subjected to bioassay-directed fractionation to try to identify the contaminants responsible for the estrogenic activity. Results were inconclusive.

D.5.8.2 Endocrine Disruptors—Effects of Preliminary Proposal Conservation Measures

D.5.8.2.1 Water Operations

Endocrine disruptors are a diverse group of chemicals, and it is not possible to evaluate fully the potential effects on the distribution and bioavailability of these chemicals from preliminary proposal water operations, and the resultant changes to mixing in the Delta.

D.5.8.2.2 Restoration

Given current knowledge, there is potential for endocrine disruptors associated with pesticides to be present in ROA soils and mobilized by inundation of ROAs. Because the chemical characteristics of this group are diverse, the compounds may become mobilized and more bioavailable as suspended particulates in the water column, or in the dissolved phase within the water column. The type of endocrine disruptors and the possibility of mobilization would need to be evaluated on a site-specific basis, taking into consideration the types of pesticides historically used on the property.

D.5.8.3 Other Stressor Conservation Measure 13, Nonnative Aquatic Vegetation Control

Other Stressor CM 13, Nonnative Aquatic Vegetation Control, would involve applying existing methods used by the DBR's Egeria densa and Water Hyacinth Control Programs. Following is a brief summary of the types of herbicides used and the known toxic effects.

DBR uses five common herbicides, including Weedar 64® (2,4-D), Rodeo® (glyphosphate), R-11® (NP & NPE), Sonar® (fluridone), Reward® (diquat) and Komeen® (copper). Table D-6 from Riley and Finlayson (2004) depicts the detected concentrations in the environment and the LC50 values (mg/L) for larval Delta smelt, fathead minnow, and Sacramento splittail.

Table D-6. Summary of Toxicity Testing for Invasive Species Herbicides

Herbicides and Surfactant	Highest Detected Concentration	Smelt LC_{50}	Fathead LC_{50}	Splittail LC_{50}
Weedar 64® (2,4-D)	0.260	149	216	446
Rodeo® (glyphosate)	0.037	270	1,154	1,132
R-11® (NP & NPE)	0.167	0.7	1.1	3.9
Sonar® (fluridone)	0.012	6.1	5.7	4.8
Reward® (diquat)	0.110	1.1	0.43	3.7
Komeen® (copper)	0.800	1.4	0.31	0.51

Rodeo®, Weedar 64® and Sonar® 96-h LC50 values for the three fish species are several orders of magnitude higher than detected concentrations in the environment and would not be expected to cause lethal or sublethal effects in larval fish (Riley and Finlayson 2004). However, the LC50 values for Komeen®, Reward®, and R-11® are lower and approach the levels found to be present in the environment, with the highest concentrations of copper (.8) being above the LC50 values for both fathead minnow and splittail larvae (Riley and Finlayson 2004). However, these copper levels were reduced to background levels within 24 hours of application (Anderson 2003). Reward® concentrations found in the environment approximate the highest concentrations in the environment, and there are indications that Reward® is causing toxicity to larval fish (Riley and Finlayson 2004). Possible mitigation measures would be to limit the application to when larval fish are not present. R-11® is a surfactant used with both Rodeo® and Weedar 64®. R-11 was virtually undetected in the environment and can be controlled by careful application only on plant surfaces (Riley and Finlayson 2004). In conclusion it is unlikely that acute toxicity or sublethal effects occur with the application of herbicides, with the exception of Kommeen® and Reward®. Exposure levels are less than acute toxic levels and have short lives within the environment. Sonar® should be more closely examined because of its longer persistence and requiring repeated treatments in the same area (Riley and Finlayson 2004).

D.5.9 Other Urban Contaminants (Lead, PCBs, Hydrocarbons)

The Bay-Delta includes only 9% urban development by land area, making urban contaminants generally a minor component of the toxins present in the Delta system. The primary Delta urban centers are located within both the Sacramento River watershed (cities of Sacramento and West Sacramento) and the San Joaquin River watershed (city of Stockton). Lead, PCBs, and hydrocarbons (typically oil and grease) are common urban contaminants that are introduced to aquatic systems via nonpoint-source stormwater drainage, industrial discharges, and municipal wastewater discharges. Lead, PCBs, and oil and grease all tend to adhere to soils, although some lighter components of oil and grease can become dissolved in water. Because they adhere to particulates, they tend to settle out close to the source and likely will be found at highest concentrations adjacent to the urban areas. PCBs are very persistent, adsorb to soil and organics, and bioaccumulate in the food chain. Lead also will adhere to particulates and organics but does not bioaccumulate at the same rate as PCBs. Hydrocarbons will biodegrade over time in an aqueous environment and do not tend to bioaccumulate.

Overall, the effects of preliminary proposal conservation measures, if any, should be minimal. A more detailed discussion of PCBs, an identified contaminant in the Delta, follows.

D.5.9.1 PCBs

PCBs were banned in the late 1970s, but because of their persistence in the environment, they are still found in mostly urban soils and sediments. High levels of PCBs in environmental media and fish have been studied extensively in San Francisco Bay, which historically has received large amounts of urban runoff and industrial discharge. Much fewer studies on PCBs have been conducted in the Delta, and PCBs are not recognized as a critical contaminant. However, the north Delta, the Natomas east main drain in Sacramento, and the Stockton Deep Water Ship Channel are listed on the 303d list of impaired waters for PCB contamination (CVRWQCB 2006).

Elevated concentrations of PCBs were reported in tissues of fish near Stockton (Lee et al. 2002; Davis et al. 2000). Studies by deVleming (2008) and Davis and others (2000) reveal that PCB concentrations in fish tissue samples from the north Delta and the Stockton Deep Water Ship Channel exceeded thresholds for human health. deVleming's 2005 fish tissue composite samples also found elevated PCB concentrations in the Mokelumne and Tuolumne Rivers. However, deVleming points out that as lipophilic legacy contaminants, PCBs are expected to be found in higher concentrations in older, fattier fish, such as those that were sampled. The Sacramento sucker consistently had the highest PCB concentrations in these studies but should not be considered an appropriate model for other species because of its high lipid content (deVleming 2008).

Overall, deVleming found that the results from the 2005 tissue samples indicate that while high concentrations of PCBs can be found in older, fattier fish in specific regions of the Delta (north Delta, Sacramento, and Stockton), Delta PCB concentrations are generally below Office of Environmental Health Hazard Assessment (OEHHA) screening values. In addition, deVleming suggests that his 2005 results indicate that the north Delta may be eligible for 303d de-listing. Similarly, the 2008 TMDL for PCBs in San Francisco Bay states that PCBs in the Delta are expected to attenuate naturally, thus eliminating the need for implementing action to reduce PCBs in Delta waters.

D.6 Effects of Changes in Toxins on Covered Species

Table D-7 below provides an overview of the occurrence of covered species in the Plan Area. Based on the fate and transport analyses presented in the previous sections and the description of species life history and distribution contained in Appendix A and Table D-7, the primary issues associated with toxins have been identified and are summarized in Table D-1.

1 **Table D-7. Occurrence of Covered Species in the Preliminary Proposal Regions**

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Delta smelt	Eggs	M,C **	M,C	C, S, P **	C, S, P		M, S **	M **	S, P **
	Larva	M,C **	M,C	C, S, P **	C, S, P	S	M, S **	M **	S, P **
	Juvenile	M,C **	M,C	C, S, P **	C, S, P	S	M, S **	M **	S, P **
	Adult	M,C **	M,C	C, S, P **	C, S, P	S	M, S **	M **	S, P **
Longfin smelt	Eggs	M,C **	M,C	C, S, P **	C, S, P		M, S		
	Larva	M,C **	M,C	C, S, P **	C, S, P	S	M, S	M **	S, P
	Juvenile	M,C **	M,C **	C, S, P **	C, S, P	S	M, S		S, P
	Adult	M,C **	M,C **	C, S, P **	C, S, P	S	M, S		S, P
Steelhead	Egg/Embryo								
	Fry								
	Juvenile	M,C **	M,C **	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M,C **	M,C **	C, S, P	C, S, P	S	M, S	M	S, P

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Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Winter-run Chinook salmon	Egg/Embryo								
	Fry	M,C	M,C	C, S, P	C, S, P				
	Juvenile	M,C	M,C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M,C	M,C	C, S, P	C, S, P	S	M, S	M	
Spring-run Chinook salmon	Egg/Embryo								
	Fry	M,C	M,C	C, S, P	C, S, P				
	Juvenile	M,C	M,C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M,C	M,C	C, S, P	C, S, P	S	M, S	M	
Fall-/late fall-run Chinook salmon	Egg/Embryo								
	Fry	M,C	M,C	C, S, P	C, S, P	S	M, S	M	S, P
	Juvenile	M,C	M,C	C, S, P	C, S, P	S	M, S	M	S, P
	Adult	M,C	M,C	C, S, P	C, S, P	S	M, S	M	S, P

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Sacramento splittail	Egg/Embryo	M,C		C, S, P **			M, S	M	S, P
	Larvae	M,C		C, S, P **			M, S	M	S, P
	Juvenile	M,C	M,C **	C, S, P **	C, S, P	S	M, S	M	S, P
	Adult	M,C	M,C **	C, S, P **	C, S, P	S	M, S	M	S, P
White sturgeon	Egg/Embryo								
	Larva	M,C **	M,C	C, S, P **	C, S, P			M	S, P
	Juvenile	M,C **	M,C **	C, S, P **	C, S, P	S	M, S	M	S, P
	Adult	M,C **	M,C	C, S, P **	C, S, P	S	M, S	M	S, P
Green sturgeon	Egg/Embryo								
	Larva								
	Juvenile	M,C **	M,C **	C, S, P **	C, S, P **	S **	M, S **	M **	S, P **
	Adult	M,C **	M,C **	C, S, P **	C, S, P **	S **	M, S **	M **	S, P **

Species	Life Stage	BDCP Regions							
		Yolo Bypass	Cache Slough	North Delta	West Delta	Suisun Bay	Suisun Marsh	East Delta	South Delta
Pacific lamprey	Egg/Embryo								
	Ammocoete	M,C **	M,C **	C, S, P **	C, S, P **			M **	S, P **
	Macropthalmia	M,C **	M,C **	C, S, P **	C, S, P **	S **	S **	M **	S, P **
	Adult	M,C **	M,C **	C, S, P **	C, S, P **	S **	M, S **	M **	S, P **
River lamprey	Egg/Embryo								
	Ammocoete	M,C **	M,C **					M **	
	Macropthalmia	M,C **	M,C **	C, S, P **	C, S, P **	S **	M, S **	M **	S, P **
	Adult	M,C **	M,C **	C, S, P **	C, S, P **	S **	M, S **	M **	S, P **

**Scoring based on low abundance of species/lifestage in the area.

M = mercury, **P** = pesticides, **S** = selenium, **C** = copper

Effect of toxin as result of BDCP:

	None	
	Low	
	Medium	
	High	

D.6.1 Summary of Conclusions

The preliminary proposal involves substantial restoration that would be implemented throughout the Delta over the 50-year implementation period as well as changes in water operations that could change how toxins move through the Delta. As described above, restoration in the proposed ROAs would result in flushing several constituents with toxic properties into the Delta waterways as sites are restored. Although these restoration actions will result in release of these toxins into the Delta environment, this is expected to be short-term because the toxins would be flushed out of the soils during early inundations, and once flushing is complete, no additional mobilization is expected to occur as a result of restoration.

The effects of this short-term flushing on fish are expected to be minimal because:

- Restoration would occur throughout the Delta and over time.
- Available data suggest that species exposure duration and concentration to toxins is relatively low compared to sublethal and lethal amounts.
- The long-term benefits of restoration will reduce exposure to toxins and eliminate sources.

Preliminary proposal water operations are expected to have little to no effect on toxic constituents in the Delta ecosystem. Although the Grasslands watershed has historically been a major contributor of selenium to the Delta via the San Joaquin River, mitigation of agricultural discharges and implementation of a TMDL has resulted in significantly decreased selenium loading to the Delta, which will continue to decrease.

As described above, the toxins of primary concern for fish in the Plan Area are methylmercury, selenium, copper, and pesticides (pyrethroids, organochlorines, and organophosphates). The following sections provide additional detail on the specific effects of toxic constituents on covered species.

D.6.2 Conclusion of Effects of Toxins on All Covered Fish Species

Effects on covered fish species will depend on the species/life stage present in the area of elevated toxins and the duration of exposure. Because release of toxic constituents is tied to inundation, highest concentrations will occur during seasonal high water, and to a lesser extent for short time periods on a tidal cycle in marshes. A full description of fish occurrence over the species life cycle is included in Appendix A and is integrated into the following sections where appropriate.

Minimal information is available regarding species' response to various levels of exposure to the toxic constituents of concern. However, information on the effects on salmonids is available and applicable to the ROAs, and unless species-specific information is available (i.e., splittail and selenium), it is assumed that species responses for non-salmonid species would be similar to those described for salmonids.

D.6.2.1 Mercury

Restoration efforts in the Delta have the potential to increase the exposure of fish to methylmercury flushed during the early inundation of restored tidal wetlands and floodplains, which is used for rearing for covered fish species. One area where methylmercury is predicted to be elevated is in wetlands and floodplains to be restored in the Yolo bypass.

Eggs. The exposure of salmonid, sturgeon, and lamprey eggs to increased levels of methylmercury as a result of the preliminary proposal would not occur because salmonid, sturgeon, and lamprey eggs are not present anywhere the restoration is proposed. However, splittail, delta smelt, and longfin smelt all spawn in or near areas that would be restored under the preliminary proposal and therefore have the potential for increased exposure to methylmercury. For delta smelt and longfin smelt that spawn in the Yolo Bypass or other ROAs in the west or north Delta, exposure of the eggs to aqueous mercury could range from 9 to 14 days (delta smelt) and up to 40 days (longfin smelt). Splittail exposure to eggs is even less, with eggs hatching in 3–7 days. It is not known what level of mercury would be assimilated and transferred to the larvae.

Larvae and Juveniles. Effects of increased methylmercury are expected to be minimal for fish rearing in the Delta. Henery and others (2010) compared methylmercury in Chinook salmon confined in the Yolo Bypass with those from the Sacramento River and found that the fish that reared in the Yolo Bypass accumulated 3.2% more methylmercury than fish held in the nearby Sacramento River. However, it should be noted that the mean methylmercury concentration for fish in the floodplain was 0.0567 μg/g and only two of the 199 individuals sampled had greater than 0.20 μg/g tissue methylmercury. In addition, the 3.2% increase observed should be considered in the context of the life stage.

Henery also found that free-ranging Chinook salmon that reared in the floodplain grew at a rate of 3.5% per day, compared to 2.8% per day for Chinook salmon that reared in the adjacent Sacramento River. Therefore, it appears that the increased exposure to methylmercury in rearing salmonids generally would not be high enough to elicit measureable sublethal effects. This growth dilution effect would be even more pronounced in adult fish that grow to three orders of magnitude larger over their life span, making the amount of methylmercury tissue accumulation as a juvenile insignificant (Henery 2010).

Unlike salmonids, juvenile and subadult green and white sturgeon spend considerable time in the Delta regions. Although juvenile sturgeon spend more time than any other fish species in the prescribed preliminary proposal regions, they also have the fastest growth rate of any species. Juvenile sturgeon are primarily benthivores, feeding mostly on secondary productivity in the food chain (small crustaceans, clams, etc.) so would not bioaccumulate mercury as fast as a top predator. As context for levels of effects on juvenile sturgeon, 25 to50 ppm methylmercury in their diet would be required to elicit sublethal effects (Kaufman pers. comm.). This is 125–250 times the amount of methylmercury found in Chinook salmon in the Yolo Bypass (Henery 2010), so increased levels of methylmercury within ROAs is not thought to be a problem for young sturgeon, primarily because of growth dilution and feeding low enough on the food chain to bioaccumulate methylmercury at low levels.

Larvae and juvenile splittail, delta smelt, and longfin smelt feed very low on the food chain, and similar to sturgeon juveniles described above, would bioaccumulate methylmercury at low levels. Additionally, juvenile longfin smelt occur primarily in San Pablo Bay and San Francisco Bay where no restoration or effects from water operations related to the preliminary proposal would occur. Similarly, juvenile delta smelt occur primarily in the West Delta and Suisun Bay, where elevated levels of methylmercury from restoration are not likely, and in Suisun Marsh, where the potential for elevated methylmercury is also low. However, juvenile smelt remaining in the north Delta area would experience exposure from food in the Yolo Bypass and Cache Slough regions.

Adults. Central Valley adult salmonids do not feed during their time in the Delta (Sasaki 1966) and potentially would be exposed to the elevated methylmercury produced in this portion of the Delta through absorption from water through their gills. Additionally, they tend to stay in the main channels through the Delta, rather than the shallow, slow-moving waters of wetlands and floodplains. As a result of their limited time in the estuary and the tendency to migrate in the main channels, adult salmonids are not likely to be exposed to a significantly different quantity of methylmercury under the preliminary proposal than under current conditions. Elevated mercury levels in the East Delta region could be encountered at the confluence of the Mokelumne and Cosumnes Rivers, although the number of spawning occurrences in this area by covered species is relatively small.

Adult sturgeon would be using the preliminary proposal regions primarily as a pathway for spawning migration, although they do forage in the lowest preliminary proposal regions. Adult sturgeon would not accumulate high tissue loads of methylmercury for the same reason as the juveniles, coupled with the fact that they spend little time in areas that are projected to have increased methylmercury production.

Although adult life stages of splittail, delta smelt, and longfin smelt feed and spawn in areas with potential for elevated methylmercury levels, they feed primarily on lower trophic level food sources and therefore do not accumulate methylmercury at high rates. Additionally, they are not expected to spend excessive amounts of time in these areas, so the uptake through their gills and food is expected to be minimal.

D.6.2.2 Selenium

Although elevated levels of selenium in the Delta ecosystem have been identified under the existing biological conditions, the preliminary proposal is not expected to result in effects on covered fish species. As described above, the San Joaquin River is the primary source of high selenium in the Delta but is being remediated under a TMDL. As such, the increased proportion of San Joaquin River water in the Delta would not result in an increase in selenium in the Delta. Additionally, restoration-related selenium increases will be over a short time period adjacent to ROAs.

The bioaccumulation and effects of selenium on fish have much to do with their feeding behavior. The overbite clam, *C. amurensis*, accumulates selenium and is key to mobilizing it into the food chain. It is abundant in Suisun Bay, but the preliminary proposal is not expected to increase the contribution of selenium to this area given the distance from the San Joaquin River source *(modeling results corroborate, insert when final).* Smelt, steelhead, and Chinook salmon would be expected to have low exposure to selenium as they are feeding on pelagic organisms that are able to excrete selenium at more than 10 times the rate of the benthic clam, *C. amurensis*. This is in contrast to sturgeon and splittail that are at risk for teratogenesis because of their diet preference for *C. amurenis,* and high concentrations of selenium bioaccumulated in their tissues, especially reproductive organs, liver, and kidneys. Deformities occur in developing embryos when selenium replaces sulfur in sulfur-rich hard tissues (Diplock1976). For example, recent field surveys identified Sacramento splittail from Suisun Bay (where selenium concentrations are highest) that have deformities typical of selenium exposure (Stewart 2004). Both green and white sturgeon feed on *C. amurensis* in the three lower regions (Suisun Bay, Suisun Marsh, and West Delta) but are not likely to be affected by the preliminary proposal–related changes in selenium because of the distance from the Grasslands area *(modeling results corroborate, insert when final).* Little is known about lampreys, but based on lamprey ammocoete occurrence in the Delta (mostly in the Sacramento River area), it is expected that their exposure to selenium-laden sediments and water would be minimal.

D.6.2.3 Copper

Data on the effects of copper on covered fish species are scarce, and the levels of copper through much of the Delta are not extremely high. However, copper is very mobile in an aquatic foodweb, and it will be flushed out of the formerly agricultural soils during early inundation of restoration areas. Also, there are reported accumulations of copper in the Yolo Bypass from upstream mining discharge, the sources of which since have been remediated (Iron Mountain Mines).

Mobilization of copper from increased flow at the weir at the upstream end of the Yolo Bypass, where copper concentrations are elevated, could have a temporary adverse effect on juvenile fish, namely salmonids, splittail, and smelt that rear in that area. Additionally, splittail adults, eggs, and larvae may be exposed while in the bypass. Likewise, rearing juvenile and adult salmonids and sturgeon may be exposed in other ROAs previously used for agriculture.

It is difficult to establish precise concentrations at which copper is acutely toxic to fish, as a large number of water chemistry parameters (including temperature, pH, dissolved organic carbon, and ions) can affect the bioavailability of copper to the fish population (USEPA 2007). Carreau and Pyle (2005) demonstrated that copper exposure during embryonic development of fathead minnows could result in permanent impairment of chemosensory functions but that the same exposure caused only temporary impairment in adults once copper is removed, suggesting that the specific life stage at the time of exposure also plays a role in the toxicity of copper to fish. However, the restoration would occur over time and throughout the Plan Area, and initial inundation is expected to flush copper from the restored area. For these reasons, it is not expected that the preliminary proposal would substantially change the exposure of fish to copper.

D.6.2.4 Pyrethroids, Organophosphate Pesticides, and Organochlorine Pesticides

Changes in concentrations of pyrethroids, organophosphate pesticides, and organochlorine pesticides resulting from the preliminary proposal are expected in the vicinity of agricultural land restored to marshes or floodplains. Specific areas of these elevated toxins have not been identified, but they can be expected in any of the ROAs. Restoration will take these agricultural areas out of production, therefore eliminating the source and reducing these chemicals in the Delta system over the long term. Similar to methylmercury and copper, the mobilization of pyrethroids, organophosphate pesticides, and organochlorine pesticides in ROA soils is expected to be a short-term phenomenon during the first inundations as the soils are flushed.

Pyrethroids have been shown to be lethal as low as 1 µg/l, although there are many different chemicals in this group with varying toxicities for fish. Likewise, little is known on the effects of organophosphates on fish, but elevated concentrations of organophosphates are more likely to affect the lower trophic levels that the covered fish species prey on than the fish directly (Turner 2002). As these pesticides are neurotoxins, behavioral effects are of primary concern; however, Scholz (2000) points out that the effects are not well understood. Scholz (2000) found that diazinon concentrations as low as 1 μg/l resulted in significant impairment of predator-alarm responses, and slightly higher concentrations of 10 μg/l caused the impairment of homing behavior in Chinook salmon. Organochlorine pesticides are neurotoxic, are likely carcinogenic, and have been implicated as endocrine disruptors because of their estrogenic nature and effects on reproductive development (Leatherbarrow et al. 2006). These pesticides are highly persistent and lipophilic, and as such, they strongly bioaccumulate (Werner et al. 2008). Because of their persistence in the environment and biomagnifications through the foodweb, the main concern with organochlorines is bioaccumulation in the higher trophic levels, and implications for human consumption. However, organochlorine pesticides and degradation products can directly affect fish through toxicity to lower level invertebrates on the food chain, and toxicity to small and early life stage fish, but there is little information specific to effects on individual species. Sublethal effects may include reproductive failure and behavioral changes. Ostrach's (2009) report suggests that striped bass have been experiencing reproductive failure due to organochlorine compounds in San Francisco Bay, which is likely due to concentrations accumulated through biomagnifications. Because they tend to adhere to soils and particulates, they may take longer to flush out than some of the more environmentally mobile constituents discussed above (e.g., copper).

In the Delta, fish in higher trophic levels are particularly vulnerable to these pesticides, as the chemicals will biomagnify and bioaccumulate in their tissues. These include white and green sturgeon, salmonids, and lampreys. As smaller fish at lower trophic levels, smelt and splittail can be expected to have less biomagnification of these pesticides.

More detailed analysis of pyrethroid, organophosphate pesticide, and organochlorine pesticide effects would require site-specific information, but overall the preliminary proposal is not expected to substantially increase the potential exposure of fish because restoration would occur over time and throughout the Plan Area, and sources would be eliminated as areas are restored.

D.7 References

D.7.1 Printed References

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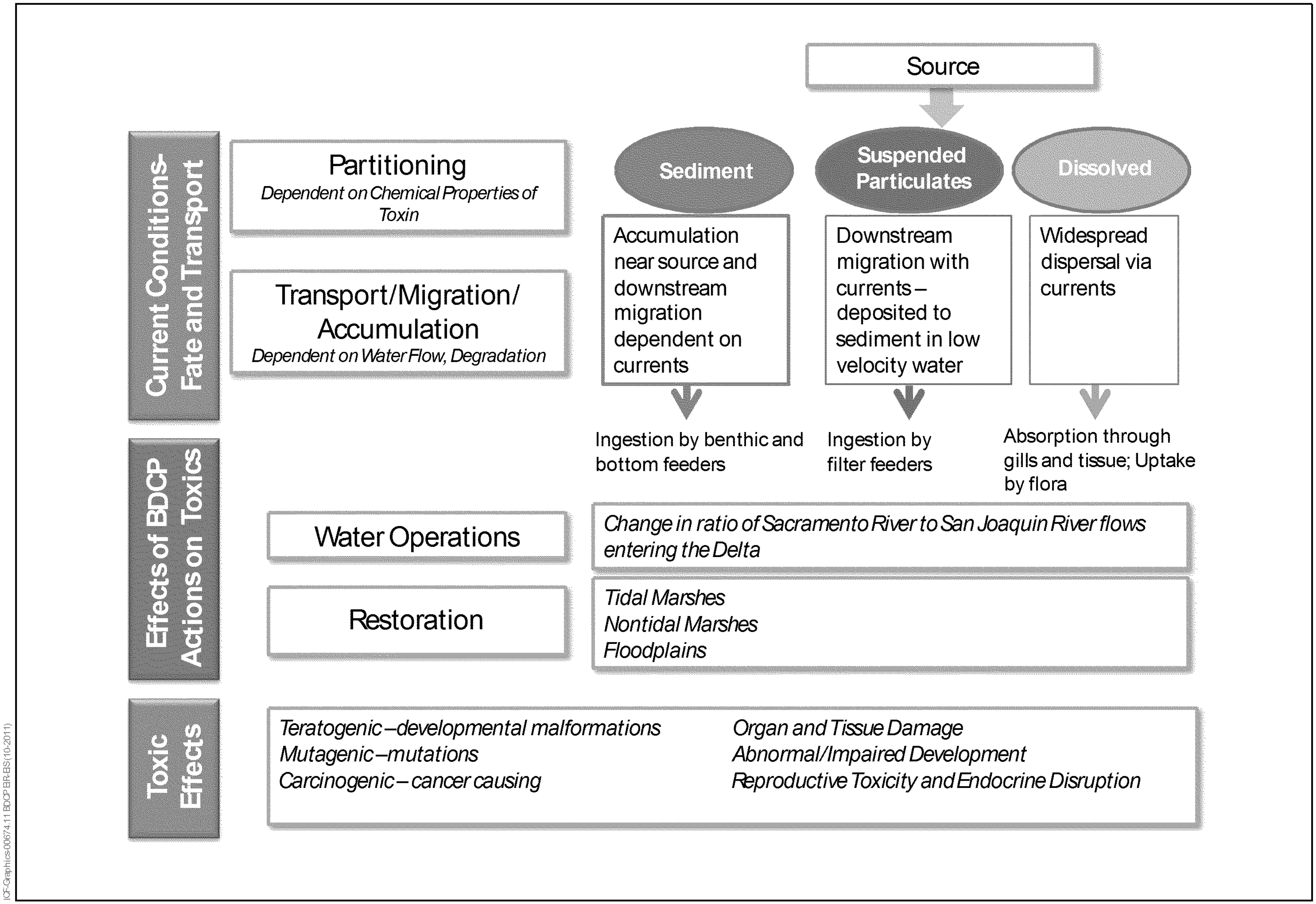

Figure D-1
Generic Conceptual Model to Evaluate BDCP Toxins Effects

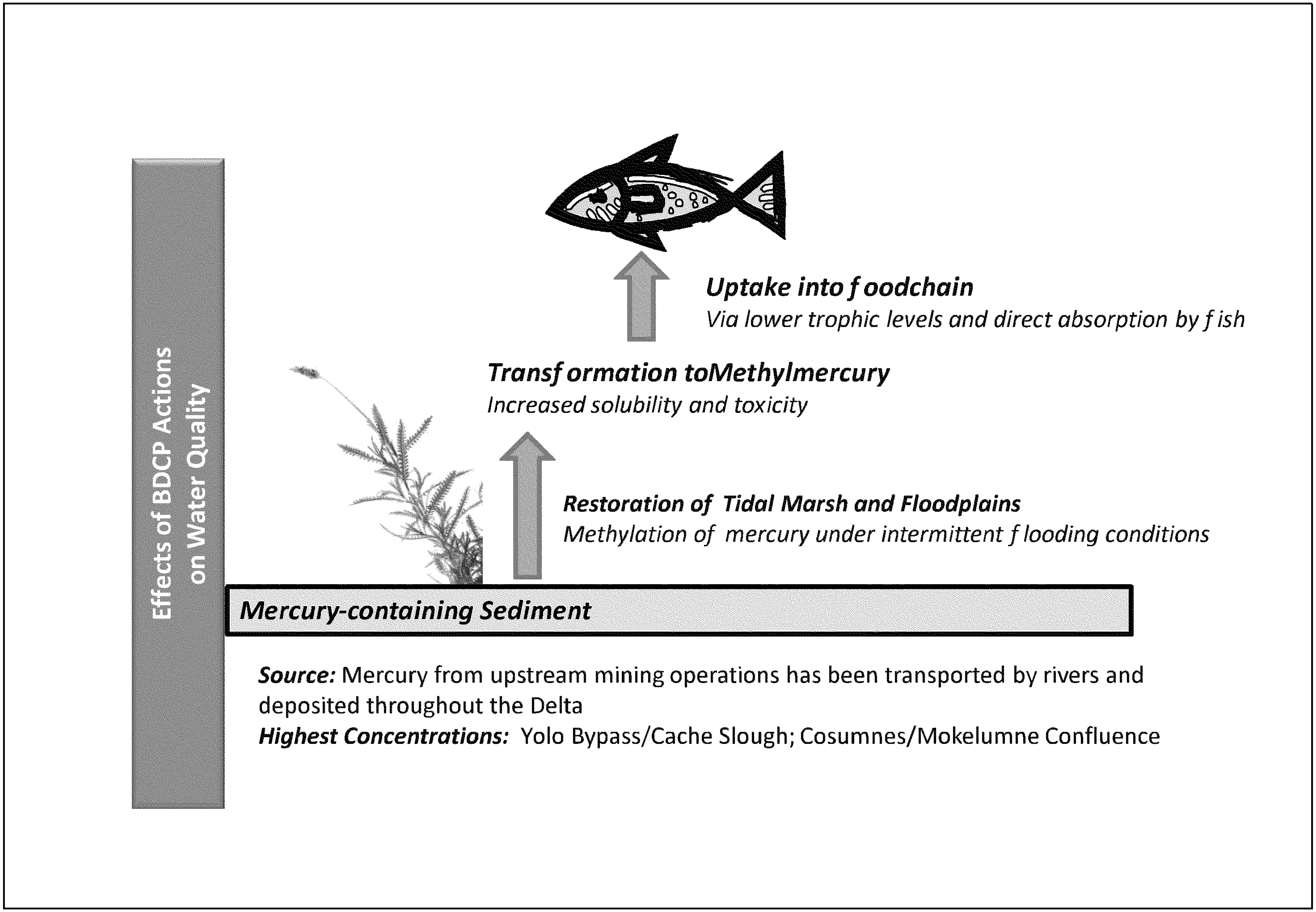

Figure D-2
Methylmercury Cycling in an Aqueous System

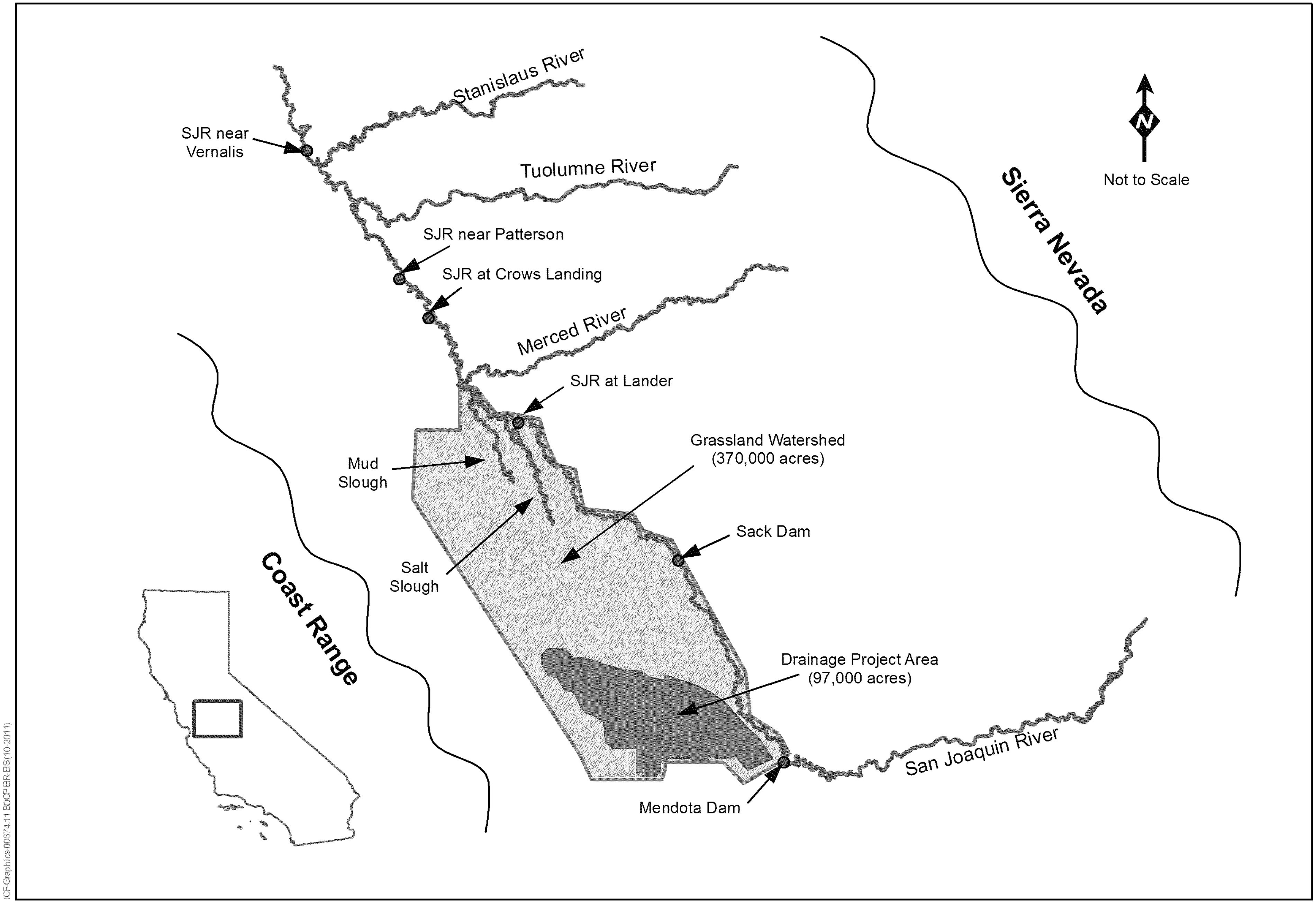

Figure D-3
Location Map for Grasslands Project Area